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Water Purification in Rural South Africa: Ethical Analysis and Reflections on Collaborative Community Engagement Projects in Engineering

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***Abstract* – This paper presents a sustainable development project in which University of Virginia students collaborated with University of Venda faculty, Global Sustainability Club students, and local community members to address water problems in a village in the Venda region of the Limpopo Province, South Africa. The cohort's goal was to implement a sustainable and contextually appropriate water purification and distribution system. The authors present the design and constructed process for a slow sand filtration system intended to provide clean drinking water to most households in the community. They present and analyze the successes, failures, and ethical dilemmas encountered throughout project execution. Also, the authors assess the project based on three evaluation criteria for service learning projects and explore possibilities for follow-up through the collaboration between the University of Virginia and the University of Venda. The paper ends with a reflection examining aspects of engineering community engagement projects including site assessments prior to project implementation, project timeframes, and cross-cultural institutional collaborations.**

Index Terms – South Africa, student-led research, sustainable development, water purification.

INTRODUCTION

Approximately 1.1 billion people worldwide lack access to safe drinking water.[1] In the Limpopo Province of South Africa, one of the poorest regions in the country, only 32% of children have access to drinking water on site and 24% have access to basic sanitation.[2] Diarrheal diseases are the second highest cause of premature mortality for both adults and infants in this province.[3]

The broadly recognized Accreditation Board for Engineering and Technology's criteria for engineering programs[4] describes the importance of thinking on a global scale. Graduates of an accredited program must have "the broad education necessary to understand the impact of engineering solutions in a global and societal context" (3.h). One way that the University of Virginia (U.Va.) achieves this goal is through its long history of collaboration with universities and communities in Southern Africa, including over two decades of scientific cooperation in large regional programs such as the Southern African Regional Science Initiative known as SAFARI 2000.[5] This program was "a large scale environmental and remote sensing field campaign focused on land-atmosphere interactions"[6] that helped develop a community of trust between U.Va. and several southern African institutions of higher education. To expand the scientific momentum from efforts such as SAFARI 2000, the Southern African Virginia Networks and Associations (SAVANA) consortium was created using "multi-directional, experiential learning based on…three major principles…: relationship, respect and reciprocity."[7] The consortium has arranged "various modalities of collaborative research, education and outreach activities, including distance-learning, Summer Study Abroad courses, January Term Intensive preparatory courses, semester exchanges, graduate level fellowships, and year abroad teaching fellowships" with students from U.Va. and southern Africa.[8] The authors, who were intimately involved in multiple aspects of this research collaboration, used these existing connections to plan and execute the project described here.

CASE STUDY

In Venda, a rural area in the Limpopo Province of South Africa, many people live without access to clean drinking water. The municipality typically provides taps throughout rural communities but distributes water to these taps infrequently, sometimes only once or twice a month, thus failing to provide an adequate supply of potable water. The authors collaborated with their project partners at the University of Venda (Univen) to address water problems in one of the underserved communities in this region; their goal was to determine how to implement a sustainable and contextually appropriate system of water purification and distribution. A village in the Mutale River Valley was initially selected because of the previous connections to the community through SAVANA. U.Va. students had worked with Univen students on several engineering projects in this community since 2006, including biogas digesters, solar lighting, solar disinfection (SODIS), water filtration using moringa seeds, rainwater harvesting, and small-scale slow sand filtration at a pre-school. All of the projects, except for the solar panels, had not worked properly or had been abandoned by the community after the students left; these projects could not be called "successful" by the criteria presented later in this paper. The authors' water purification project was a concerted effort to apply lessons learned from the shortcomings of previous student projects and to develop a large-scale slow sand filtration system, inspired by the previously built slow sand filter at the pre-school, which would provide clean drinking water to the entire community.

In September of 2007, the authors began building off their past experiences to conceptualize the water purification project. Eric Harshfield had previously participated in a 10-day January term course, "Ethics, Protocols, and Practices of International Research," where U.Va. students worked with students from southern Africa to learn about issues in international research and write proposals for development projects. During the summer of 2007, he also enrolled in the study abroad course, "People, Culture, and Environment of Southern Africa," which is "an intensive introduction to the complexity of coupled human-natural systems of southern Africa."[9] After the study abroad experience, he remained in South Africa to work with Univen researchers on a study of traditional medicine. During the spring semester of 2007, Ana Jemec studied abroad at the Australian National University, where she gained experience working in cross-

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cultural settings. In addition, for two summers she had interned at an environmental engineering firm where she gained exposure to water resources and water quality analysis. The U.Va. authors coupled these past experiences with their technical chemical engineering backgrounds to begin the planning stages of the project. They partnered with Elias Ramarumo, who volunteered through the SAVANA consortium to coordinate activities for a portion of the summer study abroad course. Additionally, he helped arrange transportation and accommodation for U.Va. students working on projects in South Africa and has been essential in linking U.Va. students with potential local community partners. As a native to the area, he has been effective in working with community leaders to plan village visits and had helped U.Va. students execute their projects in a culturally sensitive manner. Finally, the authors collaborated with students from the Global Sustainability Club (GSC) at Univen, including coauthor Ofhani Makhado (Figure 1). The aim of this club is to empower local students to get involved in local development projects as well as to collaborate on projects with other groups. The authors worked with other GSC students to plan the household surveys and the initial water purification system design.

FIGURE 1
Global Sustainability Club students.
Bottom row (Left to Right): Elly Mboneni, coauthor Ofhani Makhado, Humbu Siaruli
Top Row: Irene Makuya, Fhatuwani Malau, Blondi Nyango, Audrey Raedani, Gadisi Nthambeleni, Duncan Nengwenani

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Throughout the planning process, the authors met with several advisors, including Professor Robert J. Swap in Environmental Sciences and Professor Rosanne Ford in Chemical Engineering. The authors also sought advice from students that had previously completed projects, including members of Engineering Students Without Borders, and they regularly corresponded with Univen students and faculty. An in-depth analysis of the benefits and drawbacks of different types of water purification systems, including solar distillation, SODIS, ceramic pot filtration, fabric filtration, and slow sand filtration indicated that the latter was easiest to implement at the community-wide level and most likely to be effective and sustainable. Slow sand filtration is a relatively simple, affordable, and reliable technology in which water is purified as it passes through a bed of sand that sits on top of supporting gravel and an underdrainage system. At the surface of the sand, an active layer of schmutzdecke, which is made up of biological matter, breaks down the microorganisms and organic matter contaminants in the raw water. With every sand particle the water encounters as it continues through the sand, the process of adsorption further removes microorganisms and other contaminants. The resulting water that exits the filter through the underdrainage system exceeds the accepted drinking water standards.[10] For the next step of the process, the authors wrote several proposals to various funding institutions presenting this project, and through these proposals, they further qualified the goal of their project: to provide clean drinking water to a community in the Mutale River Valley. The authors received funding from the University of Virginia Institute of Practical Ethics and from Davis Projects for Peace.

When the authors arrived in South Africa, the research cohort consisting of the authors and Univen students began its involvement in the village by conducting a site assessment using Institutional Review Board (IRB) approved household surveys[11] and water sample tests. Because of the inconsistent supply of municipality water, some of the villagers had installed pipes to carry water from a river in the mountains to their homes. Approximately fifty households had paid for these pipes from the mountains out of the five hundred households in the village. Surveys of 46 households throughout the community revealed that 83% of the heads of the households believed that their water was not safe to drink (Table I); this idea was validated by the water sample tests which indicated that the piped water was contaminated with microorganisms, including *E. coli* and salmonella (Table II). Many households also reported that bilharzia (schistosomiasis) and other water-borne diseases were common.

TABLE I
HOUSEHOLD SURVEY RESULTS FROM FIRST COMMUNITY

Survey question	Summary of Responses
Average household size	5.2
Overall water use	240 L/day
Water used for drinking	28 L/day
Frequency of water from municipality	Once every 3 weeks
Alternative water sources used	28% from pipes in mountain, 60% from river, 9% from boreholes
Safety of alternative sources	83% believe water is not safe to drink
Use of boiling water	27% boil water
Use of bleach disinfection	9% use bleach

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TABLE II
WATER SAMPLE RESULTS FROM FIRST COMMUNITY

Sample*	Borehole	Pipes from mountain	Tshala River	Irrigation stream	Underground spring
HPC	31†	15†	Confluent	17†	30
mEndo	NG (no growth)	3	1	NG	NG
m-FC	NG	NG	30†	NG	NG
TCBS	NG	NG	NG	NG	NG
MCA	18	10	604	1	NLF (non-lactose fermenting)
BGA	NG	59	444	12	NG

* HPC = Heterotrophic plate count, mEndo = total coliform, m-FC = fecal coliform, TCBS = Vibrio selective agar, MCA = MacConkey Agar (enterobacteria), BGA = Brilliant Green Agar (salmonella); † Average of two plates

In the next step of the process, the cohort held a community meeting where the U.Va. students and GSC students were introduced by coauthor Elias Ramarumo, a member of the community and Monitoring and Evaluation Officer for Centre for Positive Care, a local non-profit NGO. Elias explained the history of the collaboration between the universities and the community through the SAVANA consortium, and he also served as a translator during the presentation. The U.VA. and GSC students explained the results of the household surveys and water testing and proposed a purification system using slow sand filters as a potential solution. The filters would collect water from the existing pipes leading from the mountains to the community. The system would then purify and store this water in a central location to provide access to clean drinking water for all community members. Although the community approved this idea at the presentation, the researchers later learned that the water committee responsible for the pipes wanted the system to benefit only the fraction of community members who paid for their installation. The water committee's stance was inconsistent with a primary goal of the project: to provide sustainable access to clean drinking water for the entire community. Installing separate pipes for the entire community to use would cost thousands of dollars and take many weeks; therefore, limited time and resources prevented the cohort from arriving at a feasible alternative in this village and led them to relocate their efforts to a neighboring community. In an attempt to provide the initial village with direct benefits from the interaction, the cohort provided the community with verbal and written results of the household surveys and the water sample tests; they also compiled a pamphlet outlining proper purification methods using bleach or boiling as a substitute for slow sand filtration. These documents were presented both in English and in the local language, Tshivenda.

Both villages used the same source water from the mountains; however, a vast majority of the community members in the second village had paid for instillation of the pipes from the mountain river to their community. In addition, the second community had a pre-existing water storage system to aid in the distribution of water to the households. The water storage system was located on the chief's kraal, a well-protected and respected area monitored closely by a community operator, who was responsible for turning the main water valves on and off. This constant interaction provided the ideal setting for the introduction of a new filtration system. In the proposed plan, the researchers would construct two slow sand filters and integrate them into the existing network prior to the storage system so that the households would have access to purified water (Figure 2).

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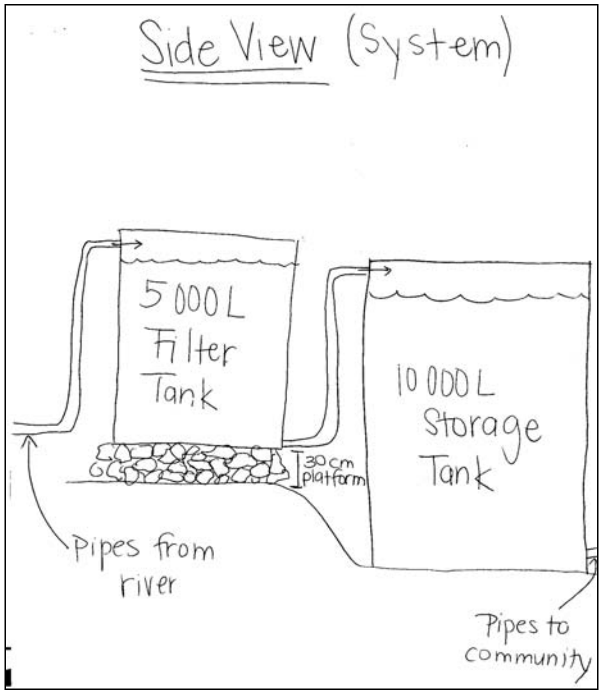

FIGURE 2
ILLUSTRATION OF THE PLACEMENT OF THE FILTERS IN THE COMMUNITY.

At the opening community presentation in the second village (Figure 3), the researchers learned that only two of the three major pipes passed through the main storage system. Due to limited time and resources, the cohort was able to complete only two filters, one for each of the main storage tanks in the system, leaving the water in the third pipe unfiltered. Instead of debating ownership of the pipes, the community members agreed that they would rather have partial access to clean drinking water than no access at all, and the households with a constant supply of purified water volunteered to provide the remaining households with a sufficient supply of drinking water. These households would use their existing unpurified water for cleaning, washing, gardening, and other activities. After the presentation, ten community members signed up as volunteers for construction and maintenance of the system.

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FIGURE 3
AUTHORS DELIVER A COMMUNITY PRESENTATION WITH TRANSLATION FROM DUNCAN NENGWENANI, A GLOBAL SUSTAINABILITY CLUB STUDENT.

The construction process for the slow sand filtration system took approximately four days and involved the ten community volunteers and the research cohort. The largest obstacle in the construction process was obtaining appropriately sized fittings for the system from the local hardware stores, and the most time consuming aspect of the process was transporting sand from the sand-pile to the filters (Figure 4).

FIGURE 4
AUTHOR AND COMMUNITY MEMBERS CARRY SAND TO THE FILTRATION TANKS.

At the final presentation following construction of the filters, the cohort explained the project and findings to the community members. They also provided a photo album of the project and a

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manual detailing the construction process, troubleshooting, and maintenance to both villages. Figure 5 shows the stakeholders in front of the completed filters. In addition, the Univen students later distributed certificates of appreciation acknowledging the efforts of the community volunteers.

FIGURE 5
AUTHORS, COMMUNITY MEMBERS, AND GLOBAL SUSTAINABILITY CLUB STUDENTS DUNCAN NENGWENANI AND SHADRACK NKOSINATHI IN FRONT OF SLOW SAND FILTRATION TANKS.

In addition to collaborating on the water purification project, the authors helped strengthen the rapidly-growing GSC at Univen. The authors offered advice and encouragement based on their experience with similar clubs at U.Va, such as Engineering Students without Borders and the Global Development Organization, thereby strengthening the connection between the two universities and enabling both sides to understand their shared vision for the future. The GSC has recently expanded their outreach to include volunteering at secondary schools in South Africa to teach youth about issues such as community development, water purification, environmental sustainability, and global warming. They also visit an orphanage in Thohoyandou where they play with the kids and donate clothes.

After the U.Va. authors left the community, the GSC continued to engage in the community and conducted water sample tests to assess the effectiveness of the slow sand filters (Table III).

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TABLE III
WATER SAMPLE RESULTS FROM DECEMBER 2008 IN SECOND COMMUNITY

Sample*	Mountain stream		Filter tank 1		Filter tank 2		Storage tank 1		Storage tank 2	
	24 hrs	48 hrs	24 hrs	48 hrs	24 hrs	48 hrs	24 hrs	48 hrs	24 hrs	48 hrs
MCA	2	2	2	3	8	4	4	5	2	4
SSA	0	0	0	1	0	0	-	-	1	-
HPC	7	8	0	7	-	-	2	8	-	-
EMB	1	1	1	2	3	5	3	3	1	5
m-FC	1	1	2	3	15	10	18	15	1	1
m-Azide	0	0	0	0	0	0	0	0	0	0

* MCA = MacConkey Agar, SSA = Salmonella Shigella Agar, HPC = Heterotrophic plate count, EMB = Eosin Methylene Blue Agar, m-FC = fecal coliform, m-Azide = m-Enterococcus Agar; (-) represent results that were either unreadable or damaged.

The fields with dashes represent unreadable or damaged results, so an additional round of water sample tests are necessary to validate the data. Because the storage tanks were not cleaned prior to introduction of the filters, the unusually high counts in the first storage tank indicate the possibility of a pre-existing contaminant in the tank. Also, the GSC students noted that the water levels in the slow sand filters were quite low, barely covering the surface of the sand. According to Huisman and Wood,[12] authors of the World Health Organization's Slow Sand Filtration manual, these filters function most effectively under constant water flow rates, with seasonal fluctuations being the hardest deviations to handle. In the Mutale River Valley, the dry season corresponds with summer (December to March), which is when the water sample tests presented in Table III were completed. One possible cause of the low water levels in the filtration tanks is a lower water level in the source river in the mountains. The decreased water levels in the tanks could have damaged the biological layer at the surface of the sand that is responsible for breaking down the microorganisms in the river water. This damage would render the filters ineffective and could account for the contamination levels found in the water sample tests. Because the filters were improperly functioning, the community elected to turn valves that would bypass the filters and revert to their previously existing system for the duration of the dry season. At the end of the dry season the community began using the filters again, and the GSC students plan to return to the community to perform an additional round of water sample tests to verify the effectiveness of the filters. A follow-up group of U.Va. students will collaborate with GSC students this summer to assess the existing filtration system, explore potential water purification methods to be used during the dry season, and address the issue of the unpurified drinking water delivered to portions of the community through the third pipe that bypasses the storage system.

ETHICAL ISSUES

Throughout the duration of the community-based participatory research project, a number of ethical issues arose. The authors learned some lessons from this experience that can inform future student-led development projects. First, researchers in student-led projects typically have preconceived notions about what they want to accomplish in a particular community. These notions are necessary because proposals for university funding require the development of a specific project idea. In this project, the authors designed a slow sand filtration system prior to their arrival in South Africa. To select this approach, they employed a rigorous evaluation procedure including significant correspondence between U.Va. and Univen, and as a result, the authors were biased towards the selection of this technology over other options once they arrived

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on site. During the initial community presentations, the authors presented the results of the household surveys and water testing and suggested that a purification system should be built. Naturally, they recommended slow sand filtration although many other useful water purification systems exist. Examples of these technologies include solar disinfection, solar distillation (SODIS), and ceramic pot filtration. Since students implementing a project during the summer have only a couple months, they cannot feasibly discuss all of the possible options with the community and spend several weeks or months selecting the most appropriate one. After much debating the community approved the technology, but the actual design was much different than originally anticipated by the authors prior to arrival because of factors such as the water flow rate, the demand, and the environment.

In addition, the relationship between nearby communities caused an ethical concern. After the authors left the first community due to the communication issues and arguments over payment of the pipes, they presented the project in the second community located nearby and explained what had previously happened. They felt it was important to maintain transparency and eliminate misconceptions about why they left the first community. Unexpectedly, this approach caused a rivalry between the communities that almost prevented the project from taking place. The researchers had frequent communication with advisors at U.Va. and Univen throughout the project and did not expect to encounter this problem. Under the given constraints, the best approach may have been to enter the second community without a preconceived idea of constructing a sand filter and without mentioning the shortcomings of the nearby community. In projects such as this one, researchers may encounter significant cultural differences that they are not aware of despite their precautions to remain culturally sensitive.

Additionally, there was an issue over compensating the community volunteers for their work. Because the project was going to benefit everyone in the community, there was an explicit understanding that the volunteers would not be paid. Ten community members signed up and put forth great effort in constructing the sand filtration systems. As a sign of gratitude, the researchers brought lunch and cold drinks each day for the volunteers. Nevertheless, the volunteers repeatedly asked for payment for their labor. A gatekeeper in the community was persistent about providing benefits for the volunteers, and the authors were worried that the project could be derailed; however, through extensive dialogue this obstacle was overcome. In retrospect, the food that the researchers provided may have suggested that the researchers would be able to provide financial compensation to the volunteers, and perhaps the certificates of appreciation would have been sufficient.

PROJECT EVALUATION

George & Shams[13] discuss three simple questions to evaluate the effectiveness of service-learning projects: 1) Have the customers' needs been met? 2) Is the project sustainable and maintainable by the customer? 3) Does the project respect the environment and make effective use of local renewable resources? (p. 68). The authors applied these criteria to this project to determine its long-term impact. In this case the customer was defined as the community where the project was implemented.

1. Have the customers' needs been met?

The needs of the community, as defined by the cohort, were to obtain sustainable access to clean drinking water for each household. Sustainable meant that a system that provided potable water would use local resources, would be affordable, and would be maintained by the

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community members. Although household surveys were used to determine if these were reasonable objectives, the community members did not have input into the design of the survey and did not have an opportunity to suggest other objectives. Therefore, customer satisfaction at the completion of the implementation phase of the project was difficult to monitor, especially since the U.Va. authors then had to leave the community. Although the community bypassed the filters during the dry season because the pipes were not supplying a sufficient quantity of water, they turned the filters back on once the water levels were restored. Through their actions, the community members indicated a desire to maintain the system. Further water testing is needed to determine if the filters are now working properly; a follow-up group of U.Va. students will return this summer to evaluate the project and continue the collaboration with the GSC and the community.

2. Is the project sustainable and maintainable by the customer?

After the GSC students reported their water testing results when they attended the January Term course at U.Va. in January 2008, the authors determined that the slow sand filters were no longer properly purifying the water as expected. These tests were conducted around the same time that the dry season started, so it is possible that the water levels had dropped below the surface of the sand and temporarily deactivated the biological layer, or that the storage tanks contained fecal coliform residue that re-contaminated the water after it passed through the filters. During the dry season, the community turned a valve to allow the water to bypass the filters and continue directly to the storage tanks. The authors did not anticipate from their site assessment and conversations with community members that the water levels in the mountains would decrease enough during the dry season to prevent the supply of water to the tanks. If the community develops alternative methods of water purification when these conditions recur, the project could be deemed sustainable. However, until alternative methods are properly established and water testing demonstrates that the filters reliably purify the water, the project is not fully sustainable.

3. Does the project respect the environment and make effective use of local renewable resources?

By integrating the sand filters into the existing storage system, the project caused minimal environmental impact in the community. Apart from scraping off the top of the biological layer every six months and then allowing it to reform, the community did not have any additional work to maintain the system. All of the materials for the project, including the tanks, sand, gravel, PVC pipes, mesh fabric, and valves were obtained from local hardware stores in Venda, effectively using available resources.

Although the project respected the environment, used local resources, and mostly met the needs of the community, the filters did not supply a reliable quantity of water throughout the year so the project is not yet fully sustainable. However, coauthor Elias Ramarumo, a member of the first community, noted that the filters are generally working well and the community is satisfied. Although problems with the water supply have occurred at times, the community members still consider the project a valuable asset. Education about water issues is very important so that the community members understand that the filters may not be working properly even when they supply a proper quantity of water. This is one of the important responsibilities of the follow-up team.

Furthermore, Elias noted that one of the most important regional goals for the future is to develop communities so that everyone has access to clean drinking water, reliable health information, employment opportunities, and better roads. The government should help improve the water supply that they provided and community members should be more involved in making decisions that concern them. Duplication of services by different organizations should also be avoided by increasing collaboration between initiatives.

REFLECTIONS

The authors extensively prepared for this project both before and throughout the academic year prior to its implementation. The preparatory steps involved intense cross-cultural engagement, coursework concerning technical engineering and non-technical social aspects of such projects, and mentoring from advisors and from students that had already completed such projects. The authors also collaborated with their Univen partners on a regular basis, encouraging the exchange of information; they researched water purification methods, wrote multiple proposals, and obtained U.Va.'s IRB approval for their household surveys.

Despite this preparation, some aspects of the project did not go according to plans, and the authors were not able to anticipate the ethical concerns that developed. An essential but oftentimes ignored step in the planning stages of a cross-cultural community engagement project should be an initial site assessment. The authors did not complete this step until they already had a solution in mind, but in retrospect, a site assessment including household surveys could have greatly benefited the authors. First of all, the authors would have engaged the community prior to selecting a water purification method; as a result, the two groups could have truly collaborated to create a sustainable solution to meet the community's needs. In addition, the authors would have had the opportunity to perform an additional set of water sample tests at a different time of year to gain a better understanding of the seasonal impact on the quality and quantity of water resources. Finally, a site assessment could have exposed the conflict concerning ownership of the pipes in the first community. Uncovering this issue during a site assessment would have provided the cohort and community members with ample time to possibly alleviate this disagreement, and ultimately, the stakeholders may have been able to design a viable solution to address the community's water quality concerns. In general, undergraduate students tend to bypass site assessments because of limited funding or because of limited time. These students fund a majority of their projects using limited grant money, and because of the relatively short timeline of the projects, travel costs to an international destination make up a sizeable portion of a student's budget and limits the feasibility of an initial site assessment during the design stages of a project.

The short timeframe within which students plan to implement projects, typically only a portion of a three month summer vacation, can impact the outcome of such projects. Even without an initial site assessment, a longer time frame could have allowed the cohort to work through the conflicts in the first community. Had the cohort still shifted its efforts to the second community, the group would have had the opportunity to complete a second round of household surveys to improve communication and better gauge the community's water needs and perceptions. Also, the authors could have held educational workshops on water issues in both communities to increase understanding of topics such as the water cycle and transmission of water borne disease. Finally, had the authors allowed for more time after construction of the slow sand filters, which require a period of approximately two weeks to form the biological layer largely responsible for the filter's purification capabilities[14], they would have had the opportunity to complete an additional set of water sample tests to determine if the filters were working efficiently. If they were not properly purifying the water, the authors could have worked with the community members to trouble shoot the system.

In general, working within existing networks can help alleviate the issues concerning site assessments and time constraints. Partnerships with a community and a local university can establish long-term relationships that provide mutual benefits. Rather than using the community as research subjects, they are treated as partners in an exchange of knowledge and resources. The research of the SAVANA consortium in southern Africa, the framework from which this project arose, is an excellent example of institutional partnerships with communities.[15] Because the water purification system did not meet all of the project evaluation criteria for a fully sustainable project, another group of students will return to the region this summer to re-assess the community's water needs and the status of the filtration system. They will continue to collaborate with the GSC and the community to determine the most appropriate next steps in the process.

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would engage the community to allow the authors to better understand the community's water needs and perceptions. These parameters would be useful in the design and implementation of a water purification system. Survey participants were randomly selected heads of households that gave oral consent. To protect the identity of the participants, the authors assigned each household an identification number and kept personal details (i.e. name, age) confidential. The surveys were delivered both in English and in Tshivenda with verbal translations by the GSC members.

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